Chapter 2

- Mechanisms: review and classifications by more examples
- Structural Analysis of planar mechanisms

Definitions and hypothesis

- A **Machine** transmit and transfer energy.
- A **Mechanism** is the mechanical portion of the machine with purpose of transferring motion and/or force from a source to an output.
- **Linkage:** consists of links (usually bars), generally rigid, connected by joints.
- We have a **mechanism** from a link chain with at least one link fixed and if at least two other links retain mobility
- We have a **structure** or **truss** if no mobility remains.
- Generally, **links** are assumed to be rigid bodies.
- **Pairs** are functions which express the joining between two links so that the relative motion between these two is consistent. There is no friction and no plays in joints.

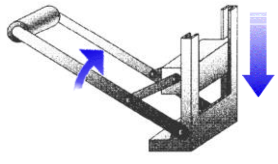
Definitions

- Degrees of mobility/Mobility (M): Number of independent parameters that define the position (configuration) of a multi-body system with respect to a coordinate axes system attached to ground element (there is a confusion of terms with degrees of freedom).
- Computation formulas:
  – in plane: $M_3 = 3\,m - 2\,l_p - h_p$
  – in space: $M_6 = 6m - 5C_5 - 4C_4 - 3C_3 - 2C_2 - C_1$

Observation: *m* is the number of mobile elements

Examples of Mechanisms

Can crusher mechanism

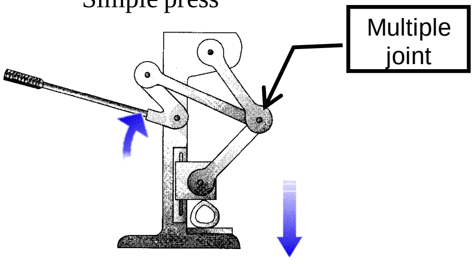


$m = 3$, $l_p = 4$, $h_p = 0$

Observation: same structure of a horizontal press mechanism is studied at Laboratory

$M_3 = 1$

Simple press

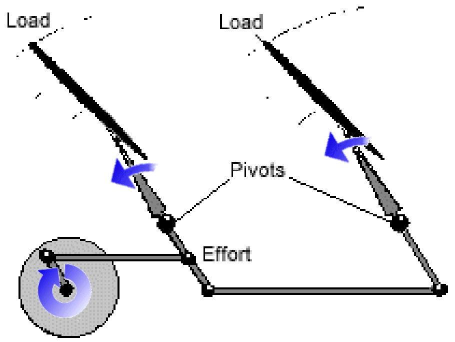


$m = 5$, $l_p = 7$, $h_p = 0$

A structure with more mobile elements is used in order to increase the pressing force

Examples of Mechanisms

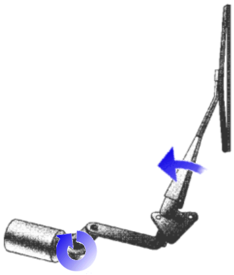
Windscreen wipers mechanism



$m = 5$, $l_p = 7$, $h_p = 0$

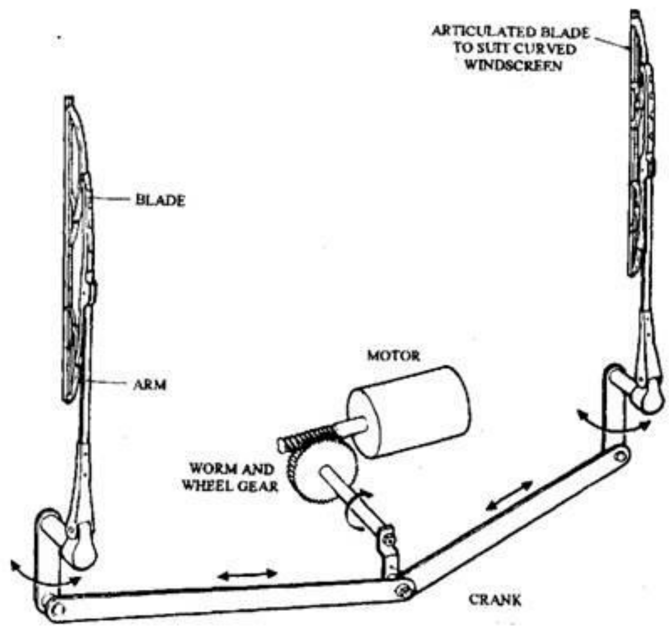
$M_3 = 1$

Rear-window wiper mechanism



$m = 3$, $l_p = 4$, $h_p = 0$

Observation: a different structure of a windshield wipers mechanism is studied at Laboratory

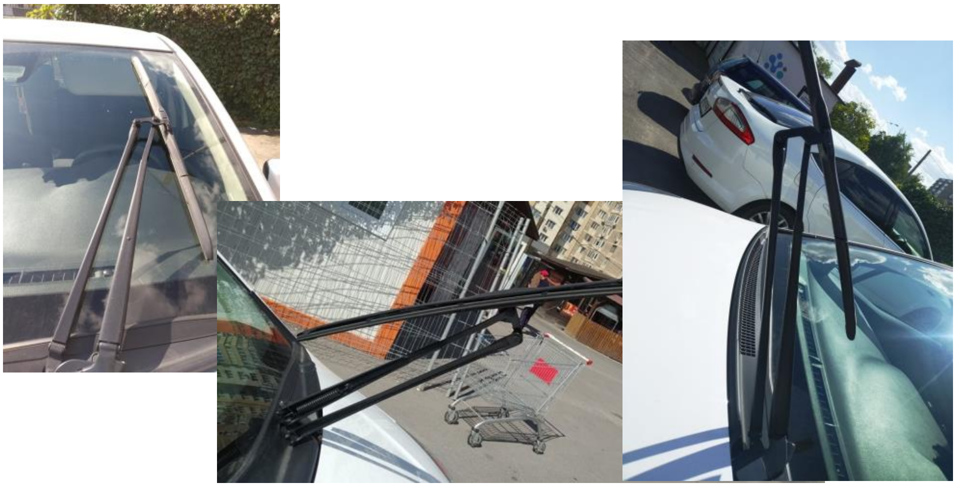


$m = 5$, $l_p = 7$, $h_p = 0$

$M_3 = 1$

Structure of the windscreen wipers mechanism is studied at Laboratory

Four-bar Mechanism used in Windscreen wipers

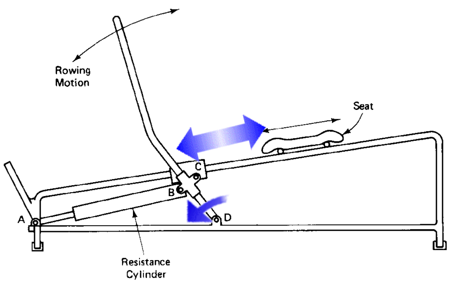


One single blade in front

$m = 3$, $i = 4$, $s = 0$ $\qquad$ $M_3 = 3\text{x}3 - 2\text{x}4 - 0 = 1$

Examples of Mechanisms

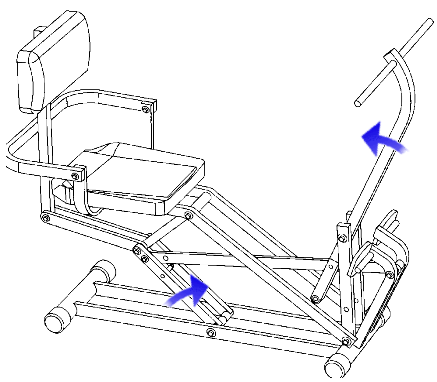
Rowing type exercise machine



Observation: seat is an independent element which is translating along railways through human body

$m = 5$, $l_p = 7$, $h_p = 0$

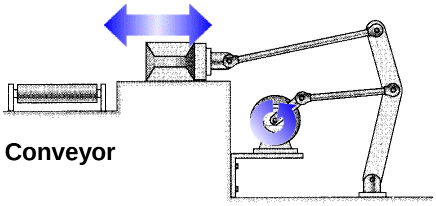
Conceptual design for an exercise machine



$m = 7$, $l_p = 10$, $h_p = 0$

$M_3 = 1$

Examples of Mechanisms

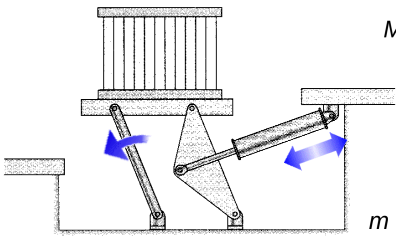


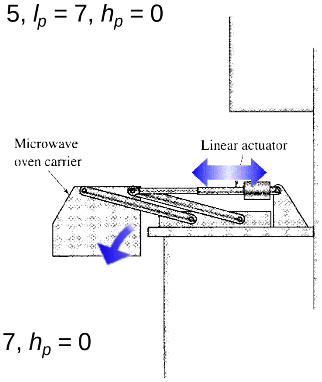
Conveyor

Moves packages from an assembly bench to a conveyor

$m = 5$, $l_p = 7$, $h_p = 0$

$M_3 = 1$





$m = 5$, $l_p = 7$, $h_p = 0$

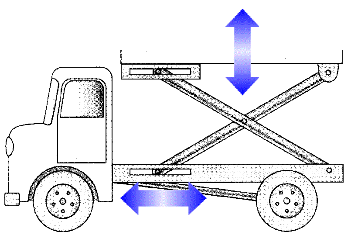
Lift platform

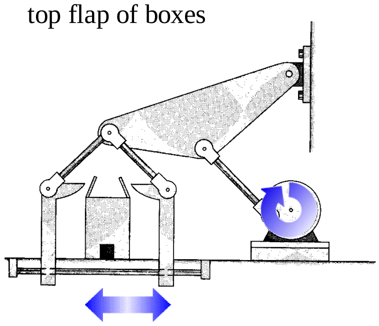
Microwave carrier to assist people on wheelchair

Examples of Mechanisms

Lift platform mechanism

Mechanism to close the top flap of boxes





$m = 5$, $l_p = 7$, $h_p = 0$

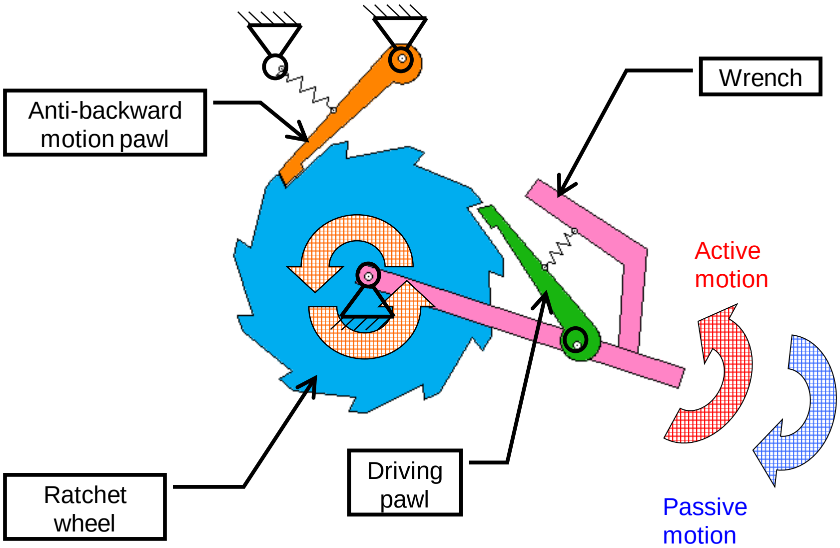
$M_3 = 1$

$m = 7$, $l_p = 10$, $h_p = 0$

Observation: In the car chassis (fixed platform) and in the movable platform there are sliders inside linear channels

Observation: Identify correctly the elements and pay attention at multiple joints !

Ratchet Mechanism



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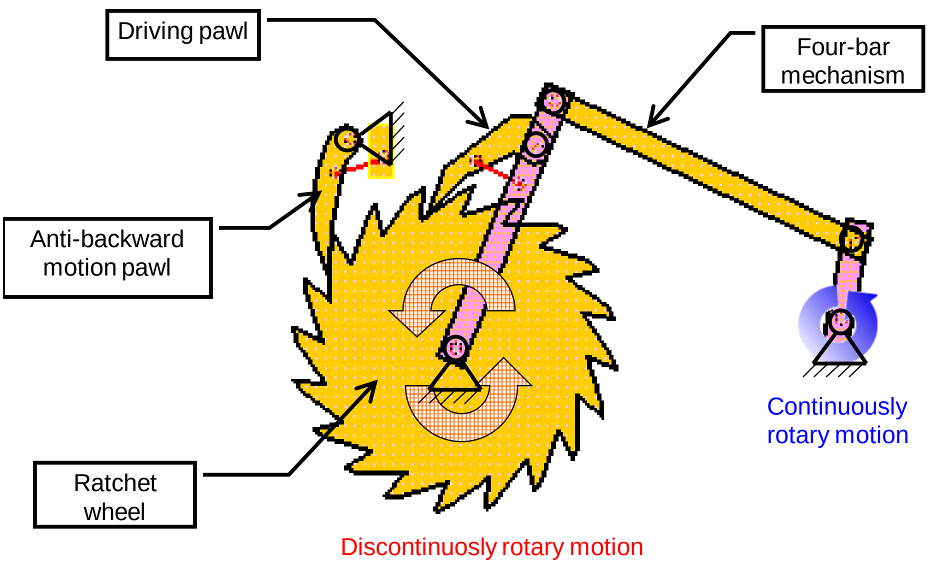
11

11

Ratchet Mechanism – powered by four-bar mechanism



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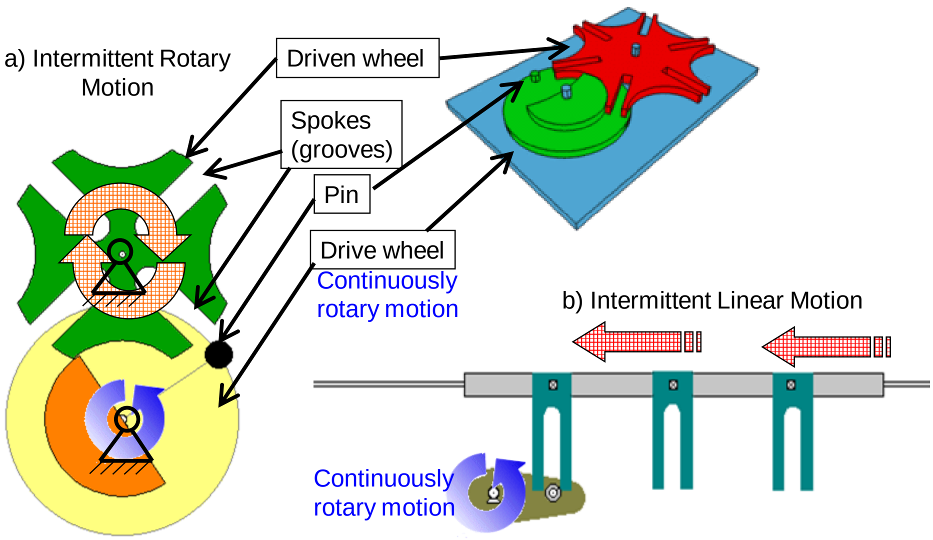
12

12

Geneva or Maltese Cross Mechanisms

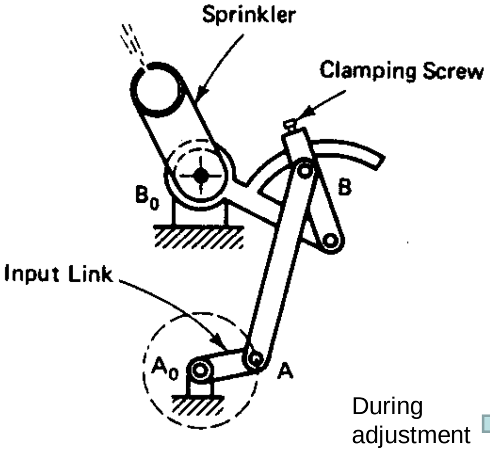


https://en.wikipedia.org/wiki/Geneva_drive

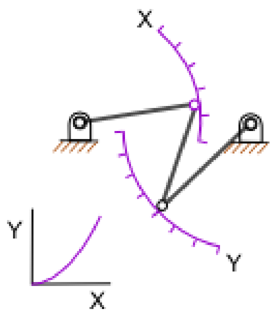
Categories of Application

- **Function Generation:** linkage in which the relative motion between links connected to the ground is of interest
- **Path Generation:** concerned only with the path of a tracer point and not with the rotation of the coupler link (ex. Cebyshev four-bar mechanism)
- **Motion Generation:** entire motion of coupler link is of concern (ex. cam-mechanisms)

Function Generator Mechanisms



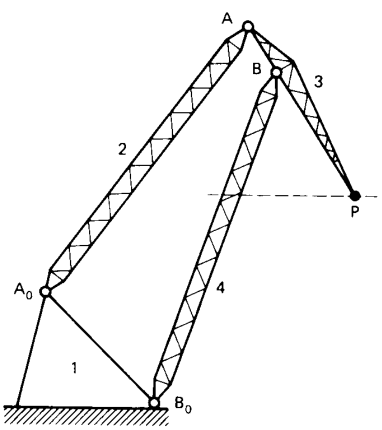
Lawn Sprinkler



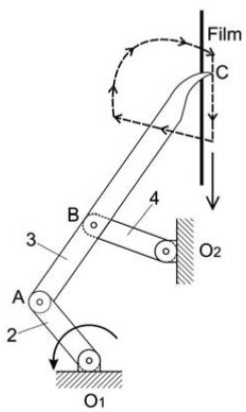
During adjustment → $m = 4$, $l_p = 5$ → $M_3 = 2$!

After adjustment → Four-bar mechanism → DOF = 1

Path Generation



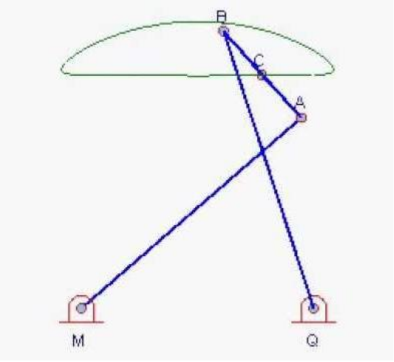
Luffing Crane – straight line motion



Camera mechanism – advancing of film with one position

Four-bar mechanisms for tracing straight lines

Chebyshev mechanism

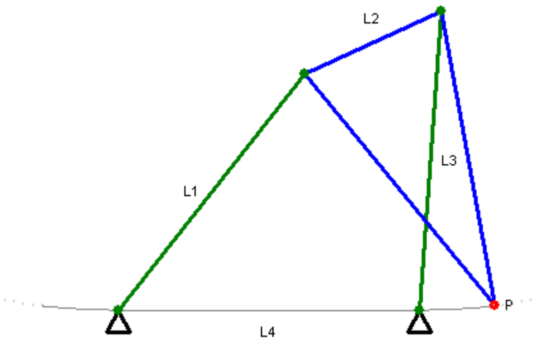


MQ:(MA=BQ):AB = 4:5:2

AC = BC

https://en.wikipedia.org/wiki/Chebyshev_linkage

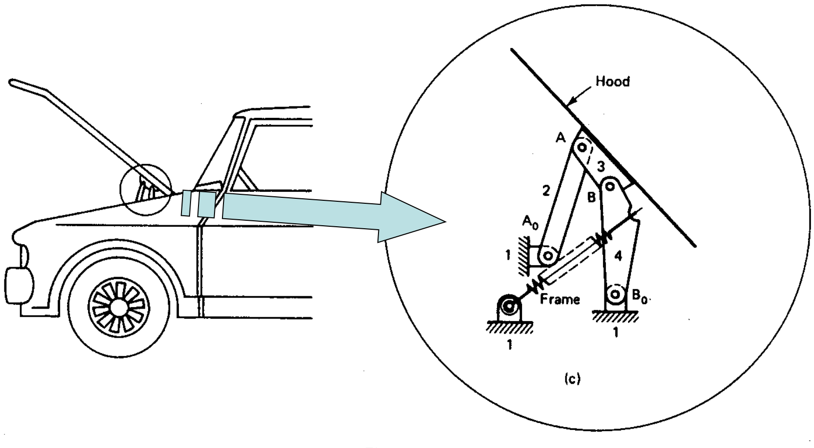
Roberts mechanism



$L_1 = L_3$ $L_4 = 2\ L_2$

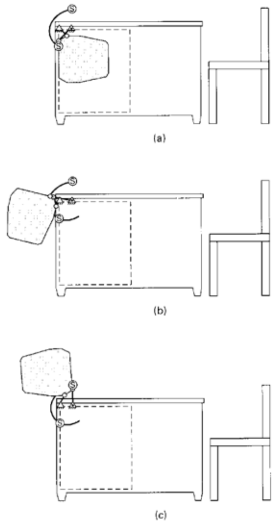
https://en.wikipedia.org/wiki/Roberts_Mechanism

Motion Generation

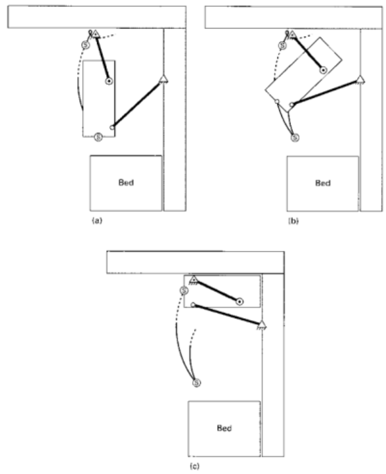


Four-bar automobile hood linkage design

Motion Generation Mechanisms

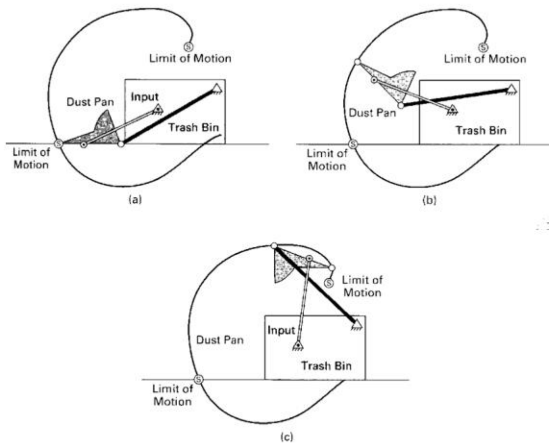


Rotating a monitor into a storage position

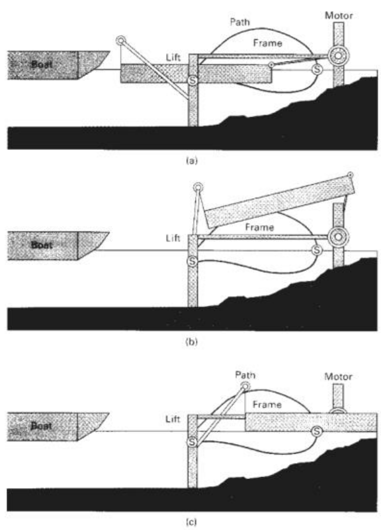


Moving a storage bin from an accessible position to a stored position

Motion Generation Mechanisms

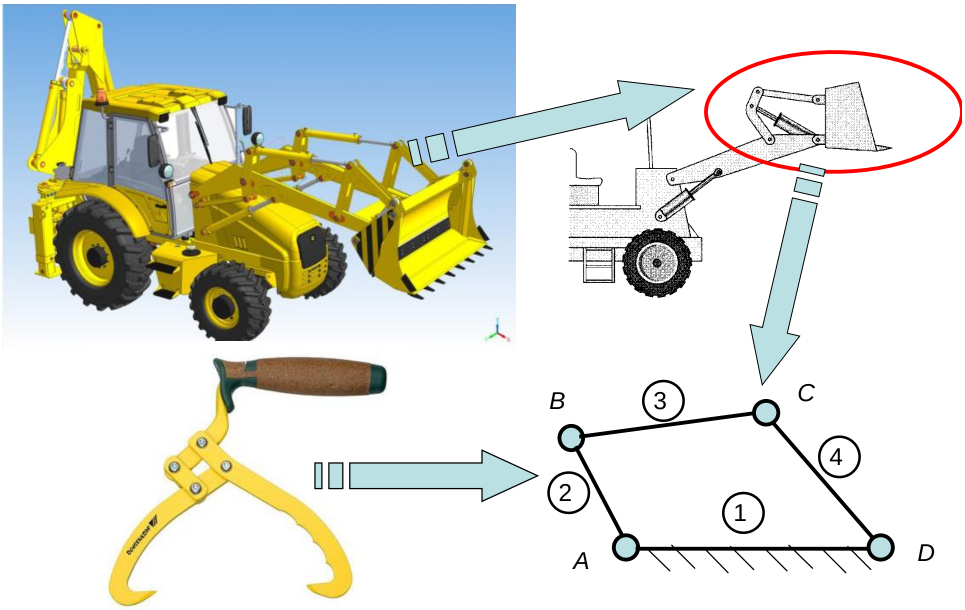


Moving a trash pan from the floor up over a trash bin and into a dump position



Lifting a boat out of water

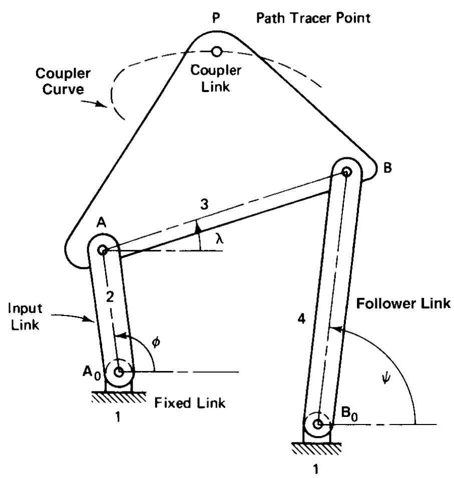
Four bar mechanism



Identify grounded element on each real mechanism

Four-Bar Linkage

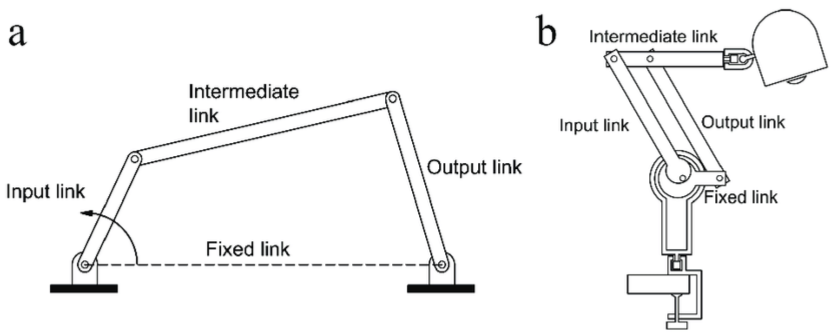
- Simplest closed-loop linkage; consists of three **moving** links, one **fixed** link (1), and four revolute (pin) joints.
- Primary links are called: the **input** link (connected to power source) denoted by (2), the **output** or **follower** link (4), and **coupler** or **floating** link (3). The latter "couples" the input to the output link.
- Points on the coupler link generally trace out **sixth order** algebraic coupler curves.



$$M_3 = 3\,m - 2\,l_p - h_p = 3x3 - 2x4 - 0 = 1$$

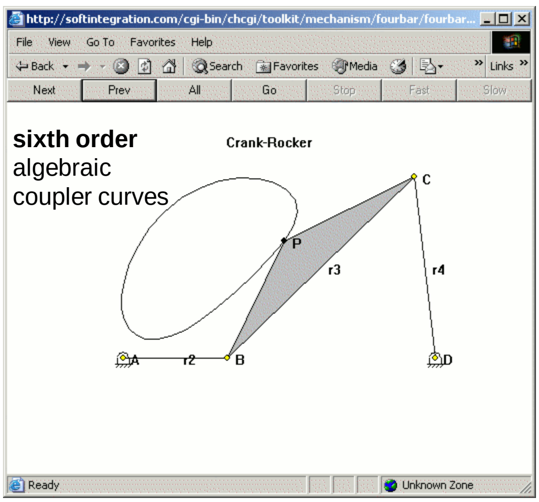
Number of independent loops: $N = l_p - n + 1 = l_p - m = 4 - 3 = 1$

Four-bar mechanism



Four-bar Mechanism (a), Four-bar Desk Lamp Mechanism (b)

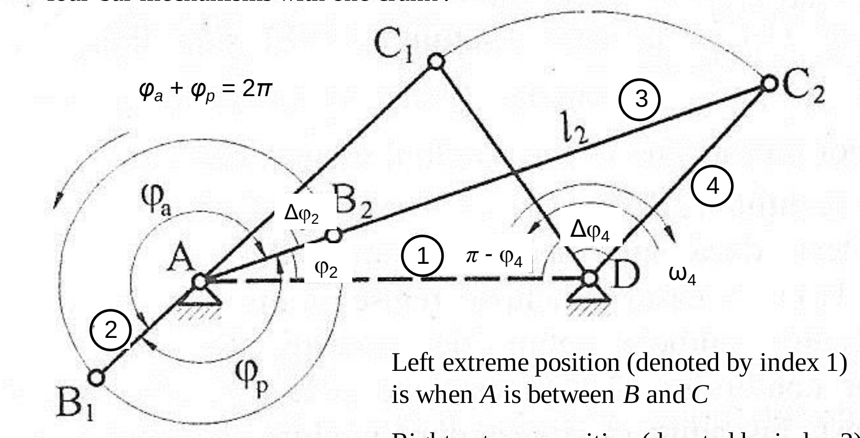
Four-bar mechanism



Simulator software: https://www.desmos.com/calculator/iuprdl6sxk

Extreme positions of four-bar mechanism (crank-rocker type)

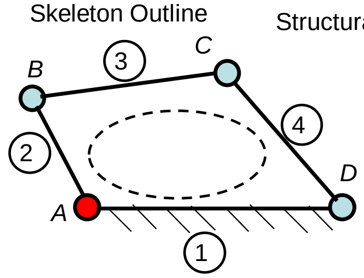
This is happening when joints *A*, *B* and *C* are co-linear in the case of four-bar mechanisms with one crank !

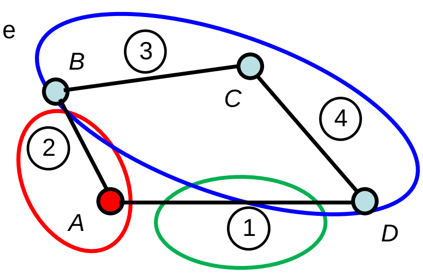


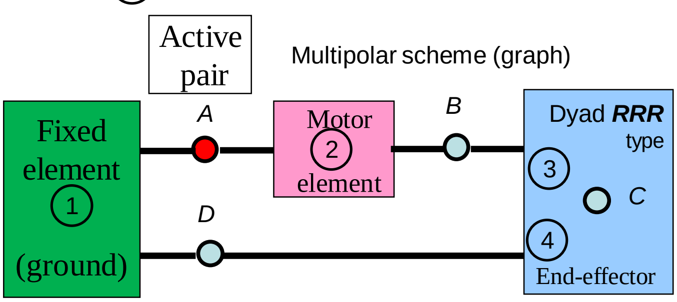
Left extreme position (denoted by index 1) is when *A* is between *B* and *C*

Right extreme position (denoted by index 2) is when *B* is between *A* and *C*

Four-bar mechanism

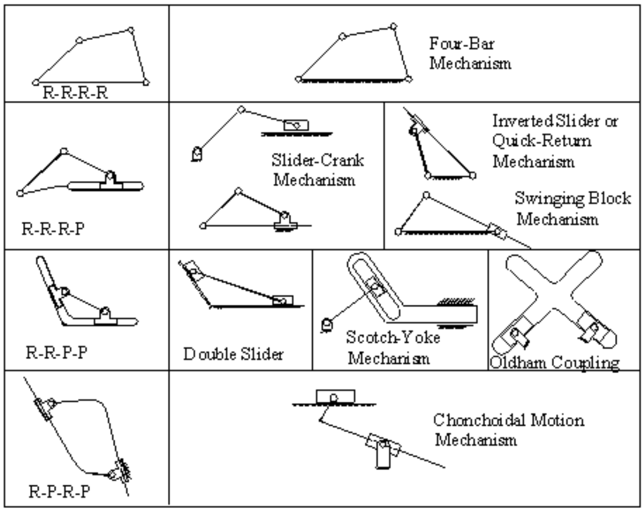




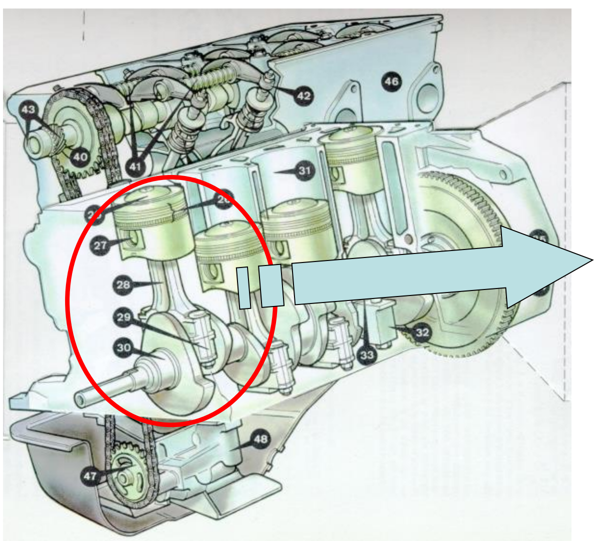


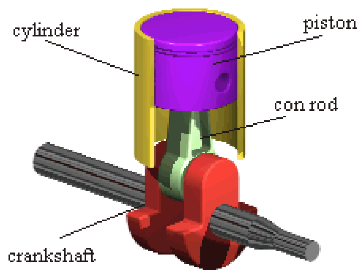
Four-bar Mechanism Family

A four-link mechanism with four revolute joints is commonly called a four-bar mechanism. Mechanisms with four joints of revolute and prismatic types and 3 mobile elements makes the “four-bar” family.

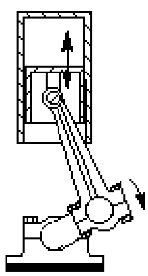


Internal combustion engine

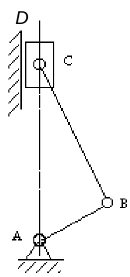




CAD model



Assembly drawing



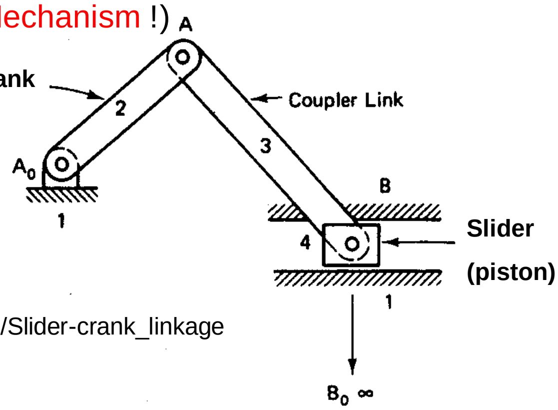
skeleton outline

Slider-crank mechanism

Slider-crank Mechanism

Mechanism of four-bar family with an element of infinite length (slider 4 which is making a linear motion i.e. a rotational motion with radius infinite !) .

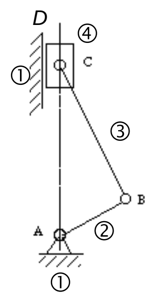
Input link is either slider 4 (which is the piston in case of internal combustion engine i.e. Slider-crank Mechanism) or crank 2 (in case of Crank-slider Mechanism !)



https://en.wikipedia.org/wiki/Slider-crank_linkage

Crank-slider Mecanism

- Mechanism of four-bar family with a single closed-loop; consists of three **moving** links, one **fixed** link ①, and four inferior joints: three of revolution pair and one prismatic pair *D* (an additional *P* from prismatic is added).
- Input element is the **crank** ②, output elment is the **slider** ④ and coupler-link ③ has a plan-parallel motion (reffered sometime as **connecting rod**).
- Points on the coupler link generally trace out **fourth order** algebraic coupler curves.



$$M_3 = 3\,m - 2\,l_p - h_p =$$
$$= 3x3 - 2x4 - 0 = 1$$

Number of independent loops: $N = l_p - n + 1 = l_p - m = 4 - 3 = 1$

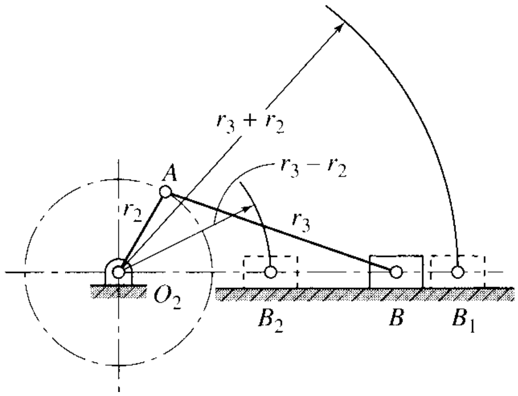
Simulator software: https://www.geogebra.org/m/DyeHXsEP

In-line "Slider-crank" Mechanism

The line of travel of the hinged joint of the slider passes through the base joint of the crank.

The stroke of in-line slider-crank mechanism is B_1B_2 (between extreme positions: B_1 at right and B_2 at left) and is two times the length r_2 of the crank.

The length of connecting rod is r_3.

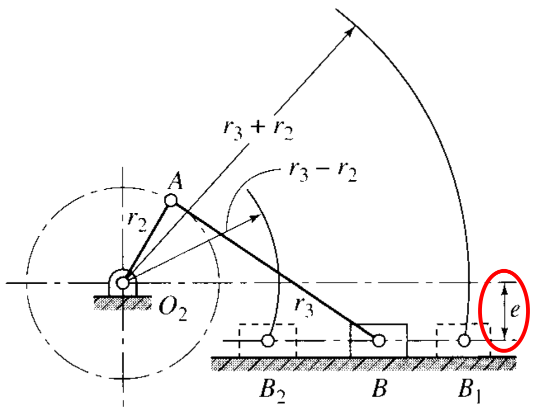


Extreme positions of in-line slider-crank mechanism are obtained by intersections between arches with minimum radius $R_{min} = r_3 - r_2$ and maximum radius $R_{max} = r_3 + r_2$ with line of slider travel, respectively

Offset Slider-crank Mechanism

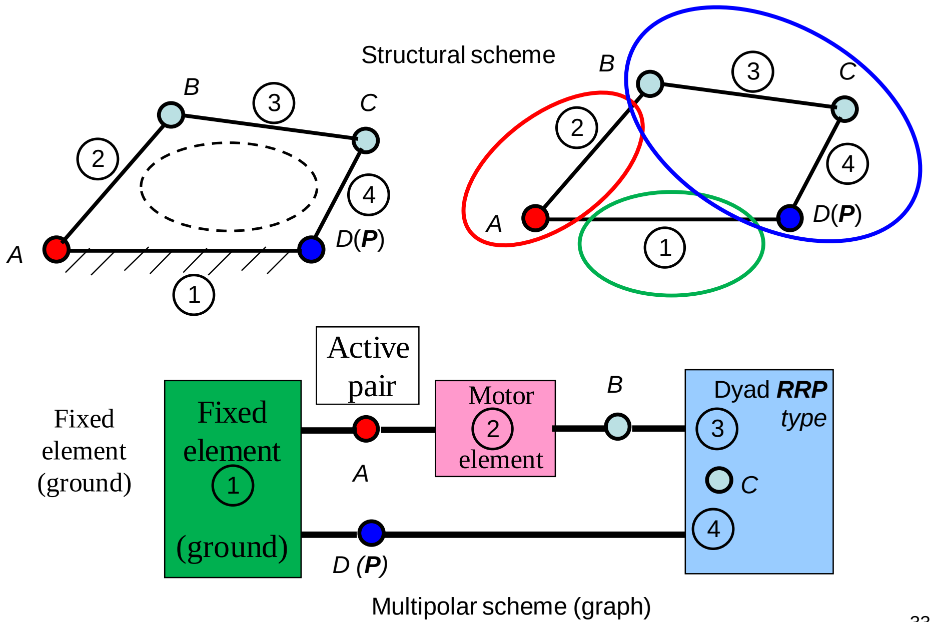
If the line of travel of the hinged joint of the slider does not pass through the base pivot of the crank, the slider movement is not symmetric (excentricity e)

The stroke of offset slider-crank mechanism is B_1B_2 (between extreme positions: B_1 at right and B_2 at left).

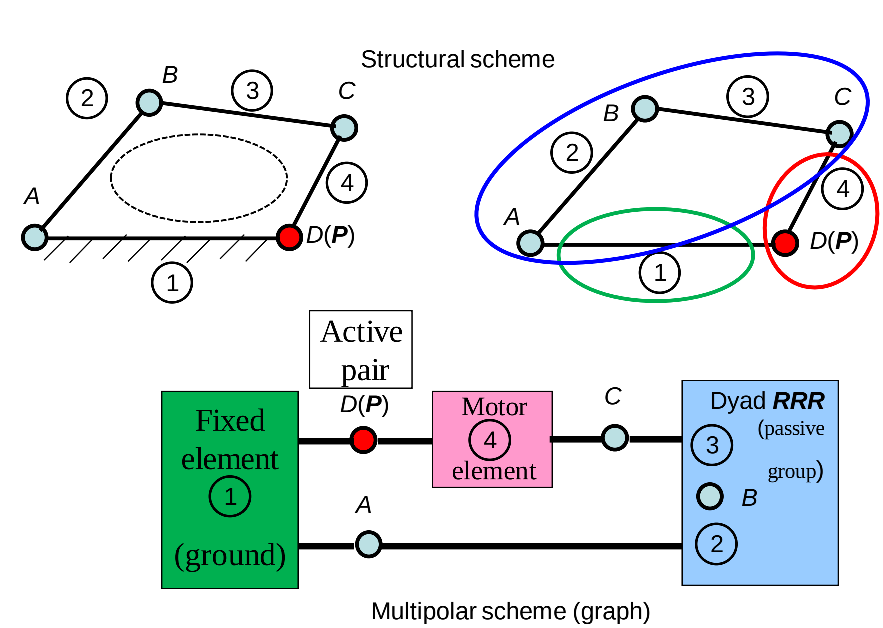


Extreme positions of offset slider-crank mechanism are obtained by intersections between arches with minimum radius $R_{min} = r_3 - r_2$ and maximum radius $R_{max} = r_3 + r_2$ with line of slider travel, respectively. Generally slider has a kinematic dimension too (represented usually by a vertical bar) so that the joint B to be not located at e distance.

Crank-slider Mechanism

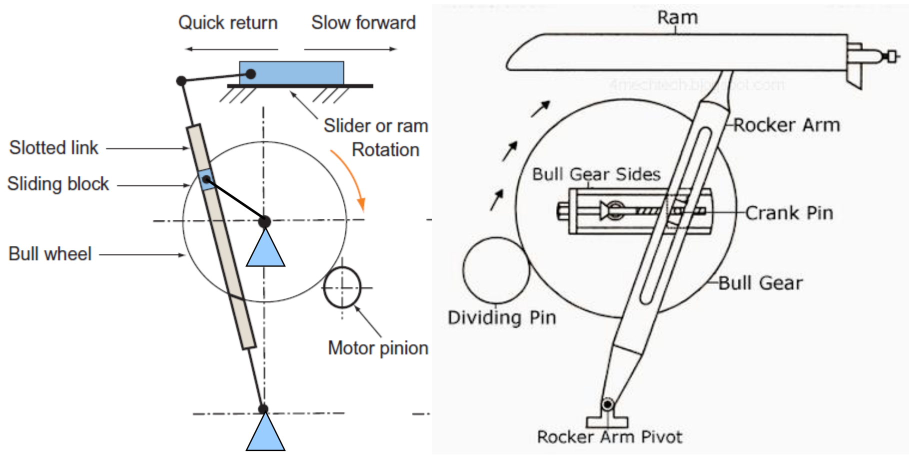


Slider-Crank Mechanism



Quick-return mechanism

Shaping machine mechanism



Quick-return mechanism

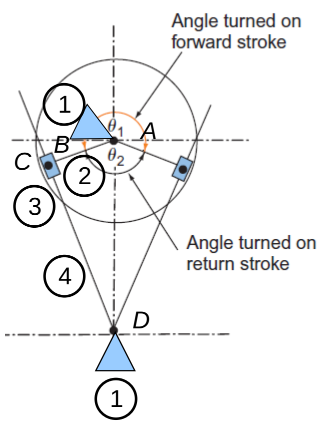
Mechanism of four-bar family with a single closed-loop; consists of three **moving** links, one **fixed** link ①, and four inferior joints:

- three revolute pairs:

A = {① , ②}; *B* = {② , ③}; D = {①, ④};

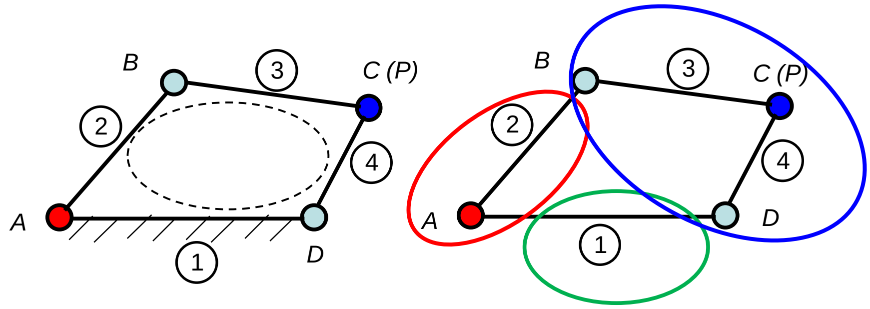
- one prismatic pair (*C* = {③, ④}).

Input element is the **crank** ②, output element is **rocker** ④ and the **slider** ③ has a plan-parallel motion.

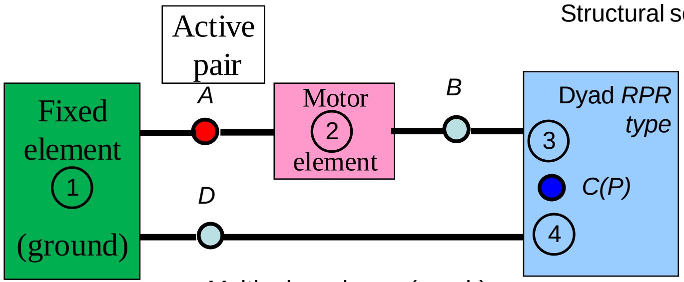


Number of independent loops: $N = l_p - n + 1 = l_p - m = 4 - 3 = 1$

Quick-return mechanism

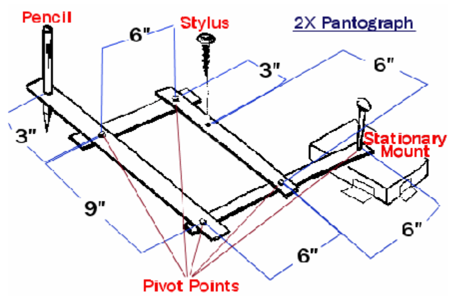


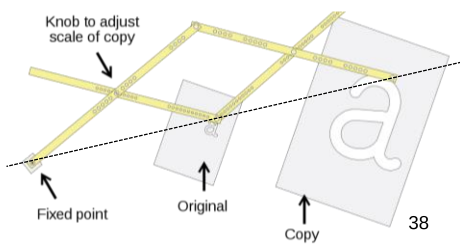
Structural scheme



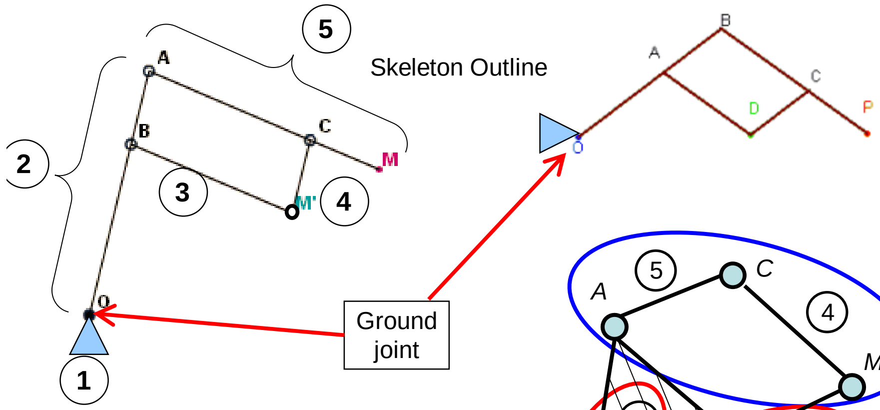
Multipolar scheme (graph)

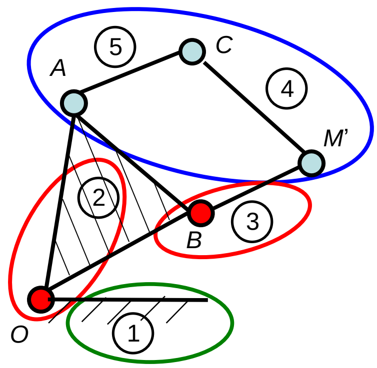
Pantograph mechanism





Pantograph mechanism





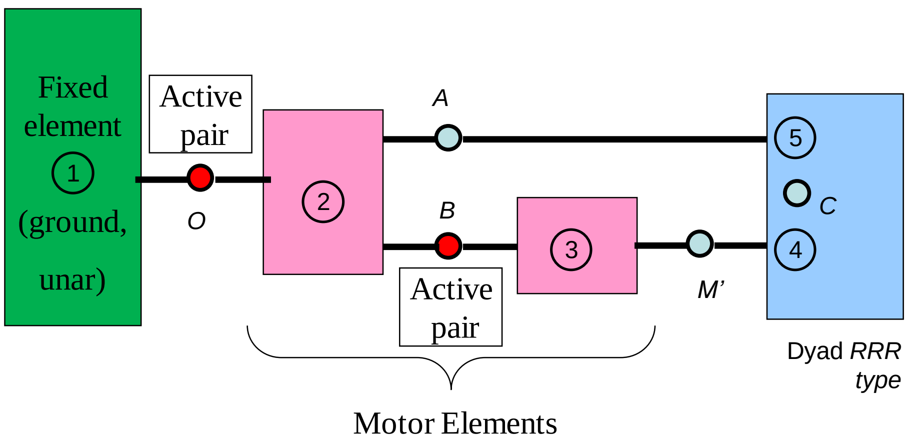
Structural scheme

Points O, M' and M are collinear

$$m = 4,\ l_p = 5,\ h_p = 0$$

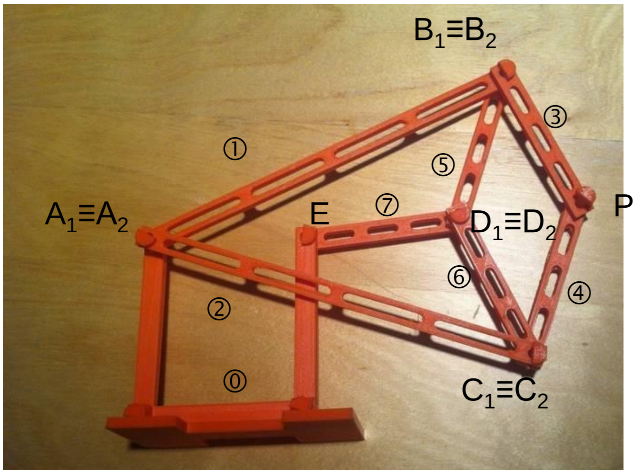
$$M_3 = 3x4 - 2x5 - 0 = 2$$

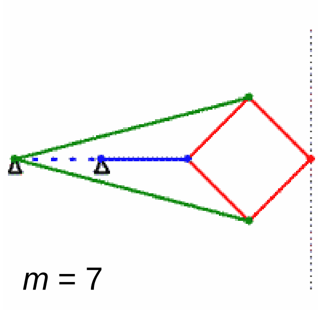
Multipolar (graph) diagram of Pantograph mechanism



$M_3 = 2$!

Peaucelier-Lipkin mechanism for tracing straight line





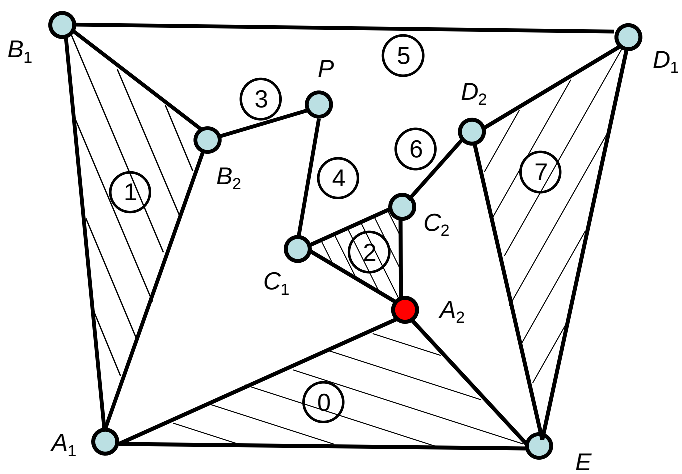
$m = 7$

$l_p = 10$ $M_3 = 1$

$h_p = 0$

Observation: there are 4 double joints $A_1 \equiv A_2$, $B_1 \equiv B_2$, $C_1 \equiv C_2$ and $D_1 \equiv D_2$;
Identify each pair between corresponding elements !

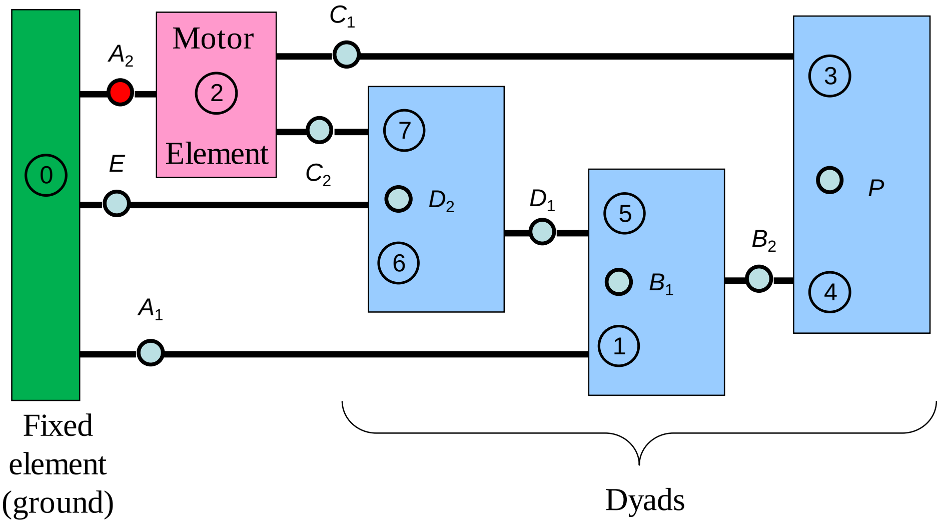
Structural scheme of Peaucelier-Lipkin mechanism

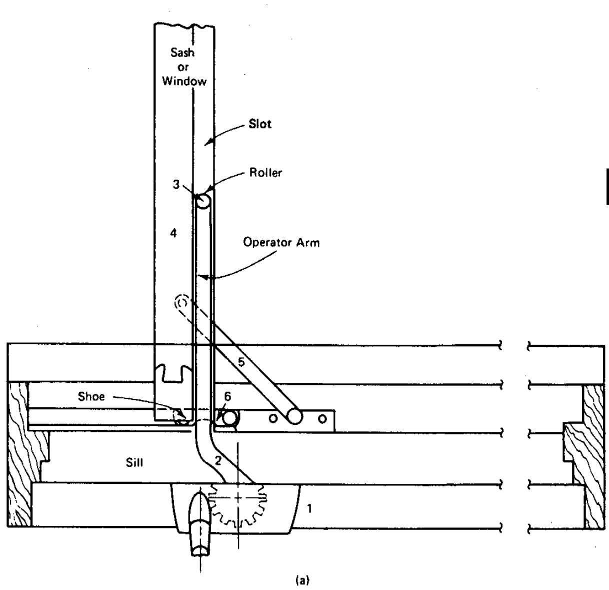


Number of independent loops:

$N = i - n + 1 = 10 - 8 + 1 = 3$!

Multipolar (graph) diagram of Peaucelier-Lipkin mechanism

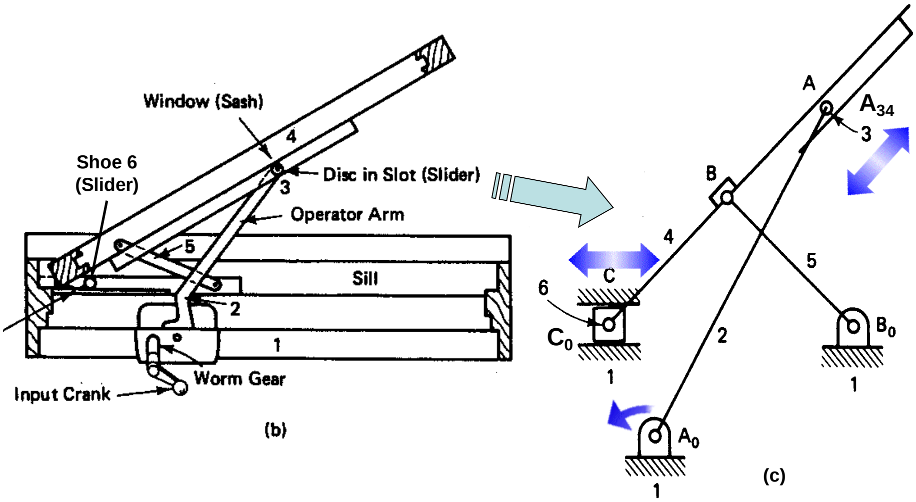




Casement Window Mechanism

Observation: The reduction worm gear between input actuating crank and the operator arm 2 is not important for this study !

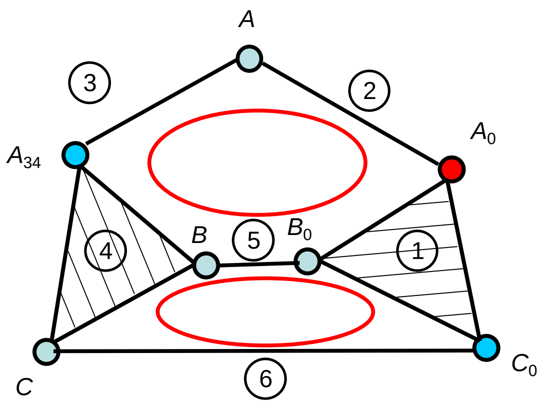
Skeleton Out-line for Casement Window



Observation: Shoe 6 and disk 3 are sliding along straight slots cut in fixed frame 1 (sill) and in windows 4 (sash) respectively

Structural scheme for Casement Window

Stephenson-type



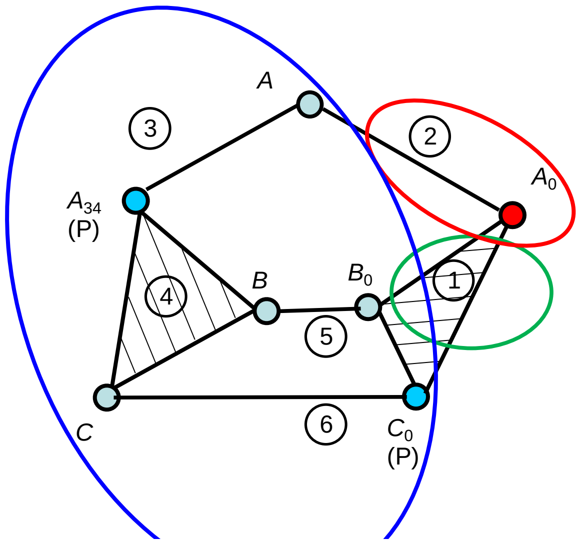
$$M_3 = 3\,m - 2\,l_p - h_p = 3\text{x}5 - 2\text{x}7 - 0 = 1$$

Number of independent loops:

$$N = l_p - n + 1 = l_p - m = 7 - 6 + 1 = 2$$

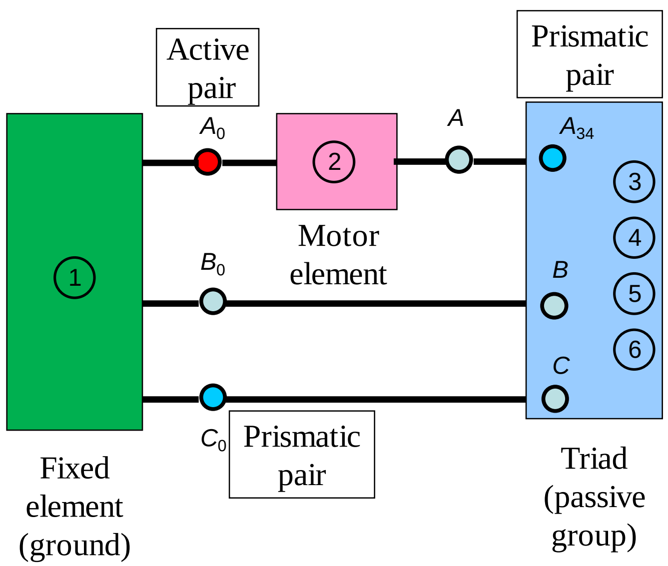
Observation: n is the total number of elements

Structural Analysis for Casement Window

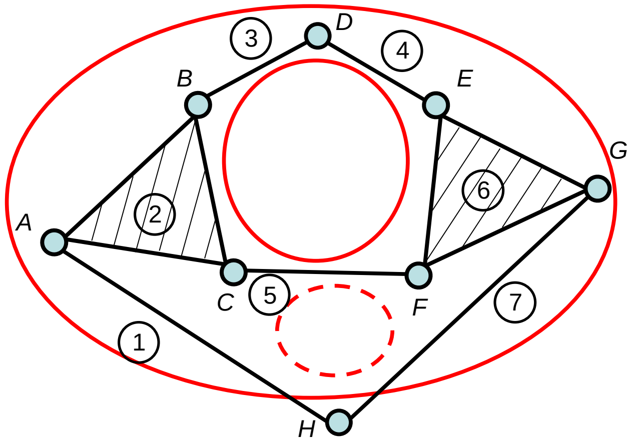


Observation: Selection of structural groups is not required for exam but is illustrative for this study and very useful in automat computation !

Multipolar (graph) diagram of Casement Window



Structural Analysis – theoretic example



Number of independent loops:

$N = i - n + 1 = 8 - 7 + 1 = 2$!

49

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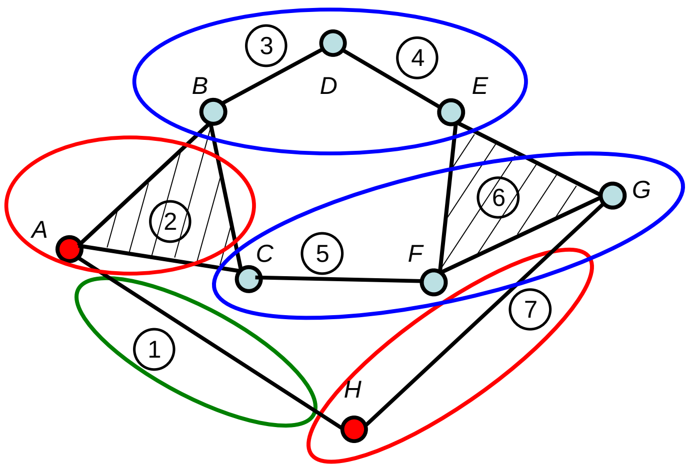
49

Structural Analysis – theoretic example



$M_3 = 3\,m - 2\,i = 3\text{x}6 - 2\text{x}8 = 2$

50

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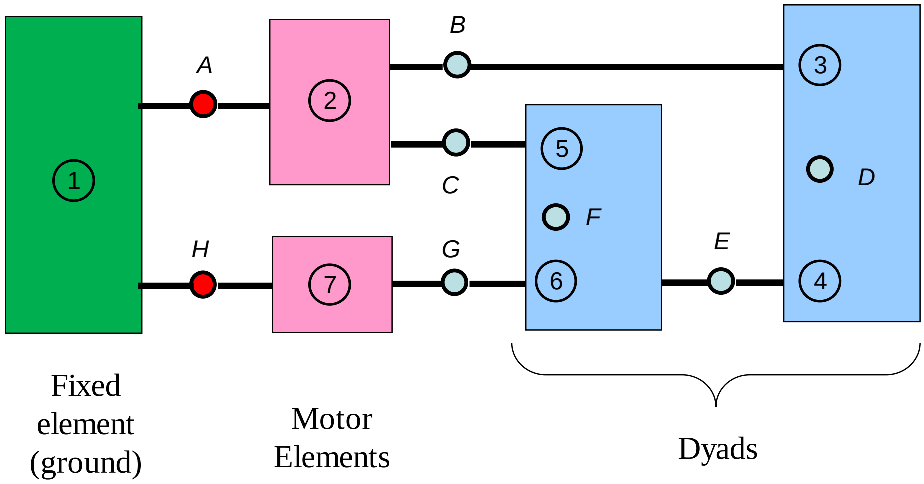
50

Multipolar (graph) diagram of theoretic example



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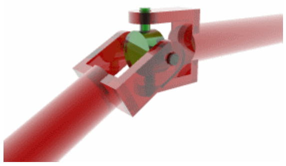
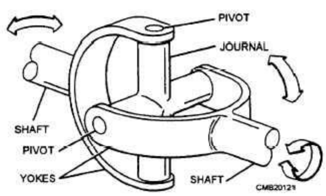
51

51

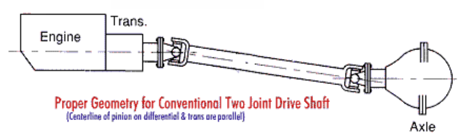
Universal joint (Cardan Joint, Hooke's Joint)





One joint (Hooke's Joint)

Linkage (with intermediary element - the "cross") of 3-rd family (spherical mechanism – all rotations have the axes concurent in the center of the "cross")



$$M_3 = 3\,m - 2\,C_5 - C_4$$

$$M_3 = 3x3 - 2x4 - 0 = 1$$

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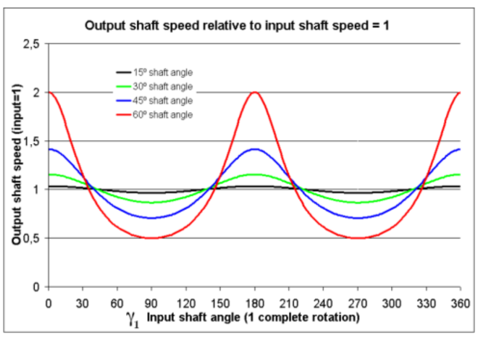
52

52

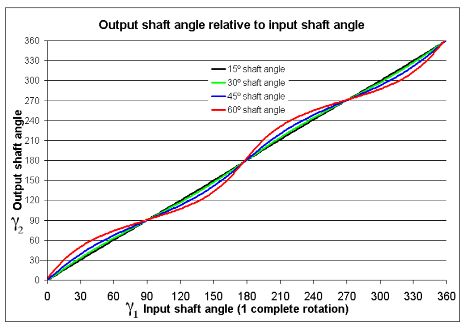
Experimental Device obtained at 3D printer

Two joints coupling (Cardan shaft, Spicer or Hardy Spicer joint)

Universal joint kinematics



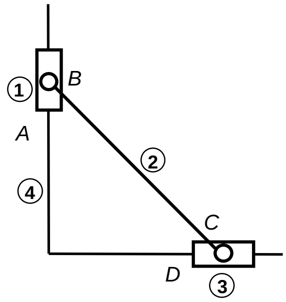
Variation of angular speed of output shaft according to different angular miss-alignment between input and output shafts, when angular speed of input shaft is constant



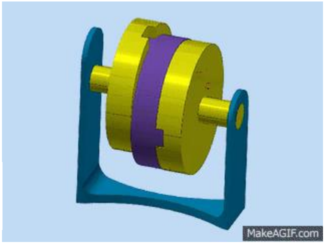
Angular variation of output shaft according to different angular miss-alignment between input and output shafts

Mechanisms obtained by kinematic chain consist of 2 sliders which are sliding along 2 perpendicular directions

Case 1: element ① or ③ is grounded



Scotch-Yoke mechanism

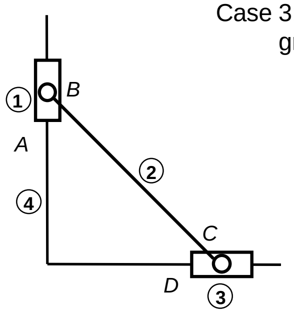


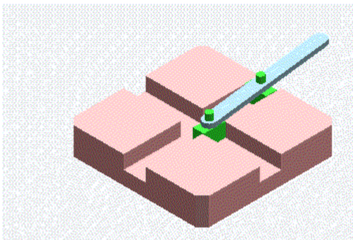
Case 2: element ② is grounded

Oldham Coupling

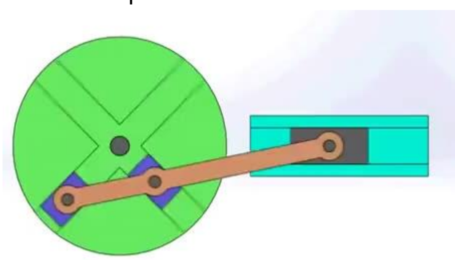
Mechanisms obtained by kinematic chain consist of 2 sliders which are sliding along 2 perpendicular directions

Case 3: element ④ is grounded

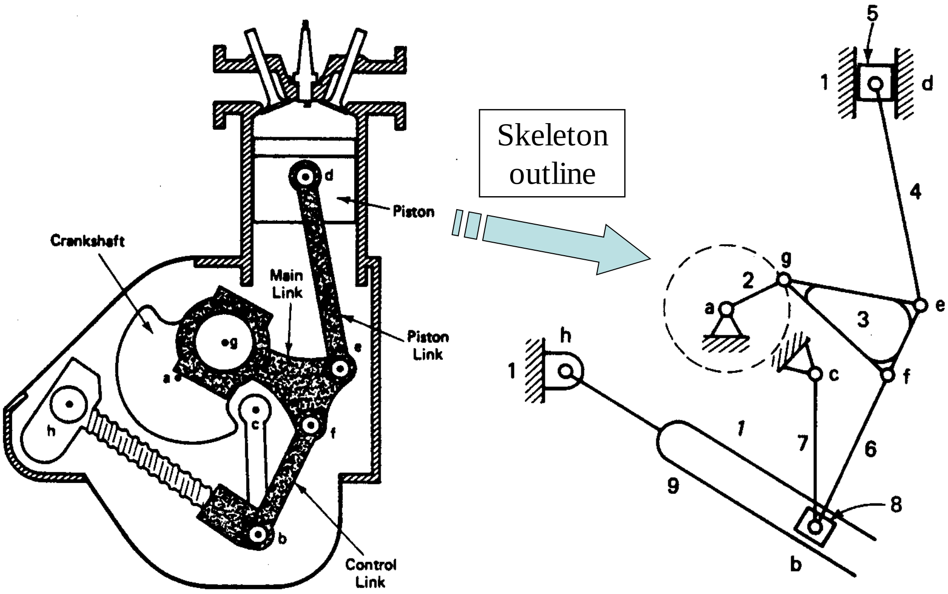




Ellipses mechanism

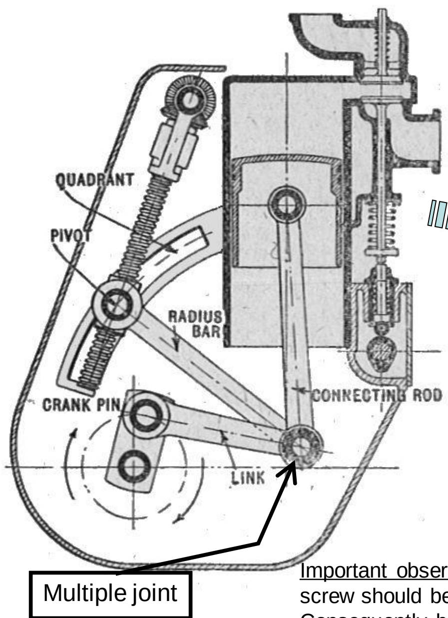


Variable Displacement Engine (example for Exam)



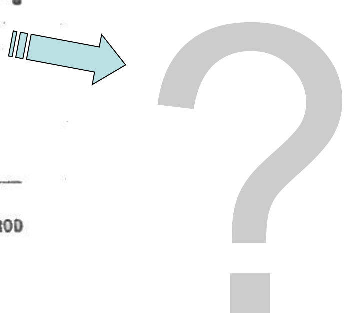
Important observation: Helical joint of adjusting mechanism with screw was equivalate by a prismatic joint; Structural scheme is required too !

Variable Displacement Engine (another solution)



Draw Skeleton outline here;

Structural scheme is required too !



Important observations: Helical joint of adjusting mechanism with screw should be equivalate by a prismatic joint as previous; Consequently bevel gear is also not important for this study !

Conclusions

- Structural scheme is just showing the structure of mechanisms. Consequently the shape of elements and the type of joints are not important (all joints are drawing as revolute joint with a simple circle just to show the pair of elements and slider is also represented as a line even it is not a bar !)
- Identify order of all elements on each presented mechanism, think the movement of each element and identify the pairs between elements on each presented mechanism.